

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

OSPAR II.1.5

NASA-CR-174313

Shortwave Infrared Detection of Vegetation



Samuel N. Goward
Department of Geography
University of Maryland
College Park, MD 20742 USA

E85-10064

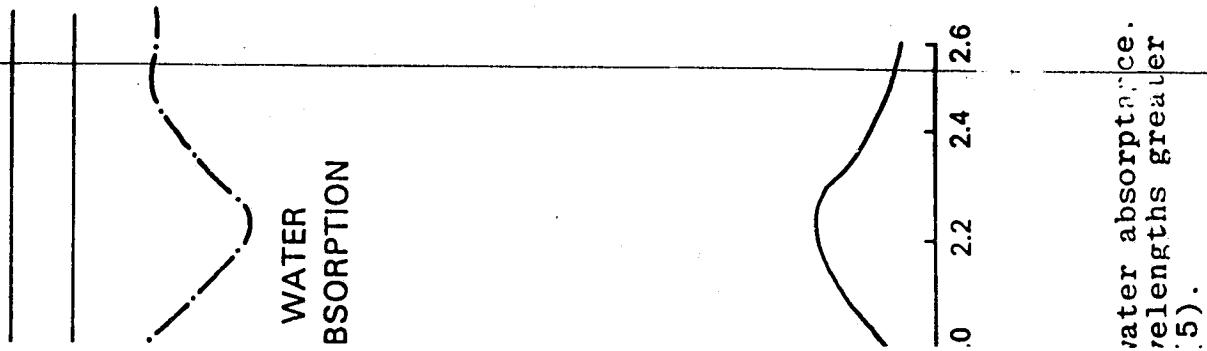
One of the most innovative aspects of the Thematic Mapper is the inclusion of sensors that record shortwave infrared (SWIR) radiation. This region of the spectrum, principally defined on the basis of living vegetation reflectance spectra, extends ~ from 1.3 μm to 3.0 μm . The predominate natural source of radiance in this spectral range is the sun, although less than 20% of the solar flux that reaches the Earth's surface falls in these wavelengths. The technology for SWIR measurements has developed more slowly than for the visible and near infrared portions of the solar spectrum. This is not only because of the low radiance available to measure but also because only limited evidence is available which suggests the information SWIR measurements will contribute in analysis of terrestrial phenomena. The former limitation is noted by Park /1/ as a primary reason SWIR measurements were not included on earlier Landsat multispectral sensors. However the latter factor has contributed to limited emphasis placed on these measurements in contemporary satellite systems (e.g., NOAA AVHRR and SPOT). Preliminary results from analysis of Landsat 4 TM measurements show that SWIR measurements provide significant improvements in discrimination of selected vegetation types /2/. The focus of this paper is to provide further evidence of the potential of SWIR measurements in vegetation discrimination based on field studies and an examination of the physical bases which cause SWIR measurements to vary with the vegetation type observed.

(E85-10064 NASA-CH-174313) SHORTWAVE
INFRARED DETECTION OF VEGETATION (Maryland
Univ.) 19 p HC A02/MF A01 CSCL 02C

N85-17402

Unclassified

G3/43 00064



Background

There is general agreement that the reflectance spectra of a single fresh leaf in the SWIR region is primarily due to water absorption /3, 4, 5, 6, 7, 8/. This can be seen by comparing the absorption spectra of pure water with leaf reflectance (Fig. 1). Primary water absorption bands occur at $1.45 \mu\text{m}$ and $1.95 \mu\text{m}$ causing reflectance minimum for leaves. The water absorption hypothesis is also supported by the observation that dehydrated leaves do not show reflectance minima at $1.45 \mu\text{m}$ and $1.95 \mu\text{m}$. In studies with cotton leaves Thomas et al /9/ found that reflectance increases with decreasing turgidity and water content particularly in the $1.3 \mu\text{m}$ - $2.5 \mu\text{m}$ wavelengths. Reflectance variations were best correlated with water content showing r^2 values between .78 and .83 in the SWIR region. Other investigators have found similar results /10/. In a later study Thomas et al. /11/ attempted to predict cotton leaf water status from leaf spectral reflectance measurements with little success. They attributed failure to variations in internal leaf structure that resulted from water availability during development.

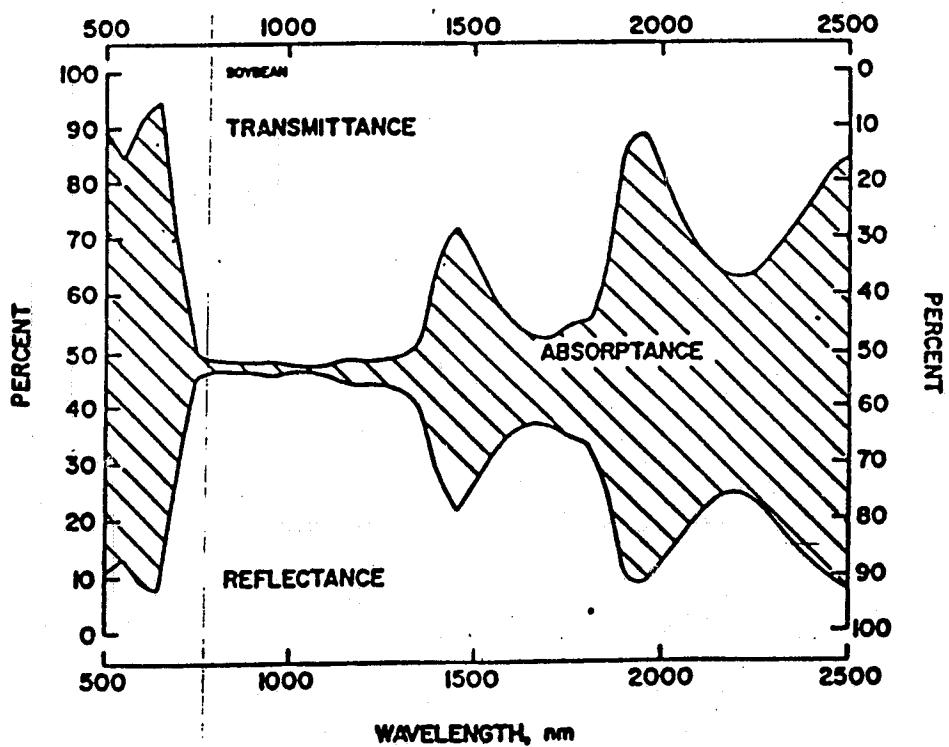
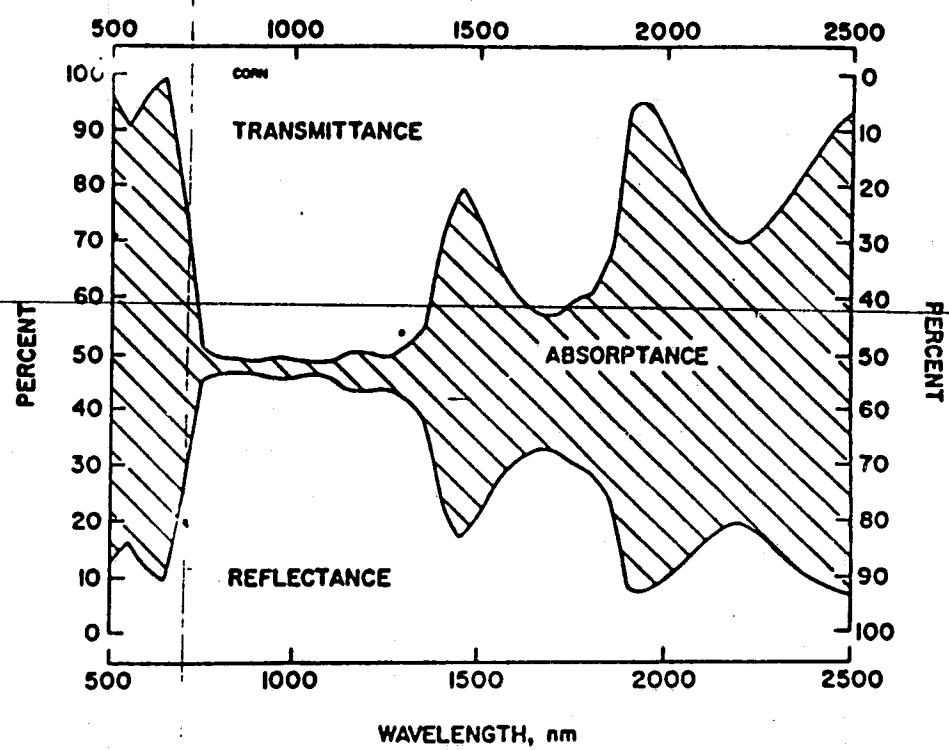


Fig. 2. Leaf optical properties for corn(a) and soybean(b) from Gausman et al. (18).

content saturate at low canopy water content levels /36/. They also note that SWIR measurements increase rapidly as the canopies go into senescence. Blad et al. /35/ found SWIR measurements contain more information as plant moisture stress than VIS or NIR measurements. Harlan et al. [89] found stressed wheat showed increased SWIR reflectance.

Summary

Previous studies show consistently that SWIR measurements provide improvements in vegetation species discrimination when compared to VIS and NIR measurements. The ability to conduct analysis of canopy moisture status with SWIR measurements is less certain and apparently more complicated. The studies presented here address the former use of SWIR measurements and the results have implications in analysis of canopy moisture status. However full evaluation of the latter use of SWIR measurements was beyond the scope of the current research.

Field Measurements

NASA AgRISTARS investigators conducted a series of field studies in Webster County Iowa from 1979 to 1982 /31/. Measurements acquired from 1980 are of particular interest because the full scope of the growing season was captured in that year (Table 1). The Webster County intensive test site is within the United States midwestern corn belt. The predominate crops are corn and soybeans. The test site was located in central Iowa at 42°N latitude and 93°W longitude. The area observed extended over a 9 x 11 km area. Within the site ~ 50 fields each of corn and soybeans were selected for intensive observations. Helicopter measurements with a high resolution spectrometer were acquired approximately every 18 days. Coincident ground measurements of crop canopy attributes were also carried out.

TABLE I

1980 FSS Observations for AgRISTARS
Study Site Webster County, Iowa

<u>Date</u>	<u>Crop</u>	<u>Conditions</u>
	Corn	Soybeans
5/08/80	Planted not up	Planted not up
5/22/80	Planted not up	Planted not up
7/01/80	Emerged	Four nodes with leaves
7/17/80	Six leaf	Beginning bloom
8/06/80	Tasseled	Full pod
8/19/80	Tasseled, Pollen shedding	Beginning seed
9/10/80	Pollen Shedding complete	Full seed
9/26/80	Kernels at blister	Full seed
10/19/80	Dent stage-Harvest	Harvested
10/30/80	Harvested	Harvested

by first normalizing the individual FSS spectral bands to nominal incident solar flux intensity per band and then summing the appropriate FSS channels. TM filter functions were not considered thus the measurements are for equivalent square-wave filters.

Analysis

Mean and variance properties for corn and soybeans were computed for each observation date (Fig. 3). The temporal trajectories of these values show distinctive patterns in the VIS, NIR and SWIR portions of the spectrum. Corn was planted for the majority of fields by 25 April and soybeans by 15 May. Early measures are predominantly from bare soils of high organic content which show low reflectance in the visible (~5%) and near infrared (~7%) and higher reflectance in the SWIR (~20%). As the crops emerge visible reflectance decreases, NIR reflectance increases and SWIR reflectance decreases. Corn grows more rapidly in the early season but tasseled by early July. Soybeans continued to grow to mid-July. This difference in growth cycles produces the "crossover" of reflectance between corn and soybeans in mid-July in the visible and near infrared bands. No such crossover is observed in the SWIR measurements.

The VIS-NIR reflectance crossover suggests that corn and soybeans can not be distinguished with these spectral measurements in the mid-growing season. The transformed divergence statistic (D^T) was employed to evaluate this hypothesis in multivariate data space (Fig. 4) /38/. Previous studies of D^T values have shown that it must exceed 1500 in order for the classes to be discriminated. Without the SWIR measurements corn and soybean are not separable in mid-season. Inclusion of the SWIR measurements eliminates this midseason loss of separability and enhances discrimination throughout the remainder of the growing season.

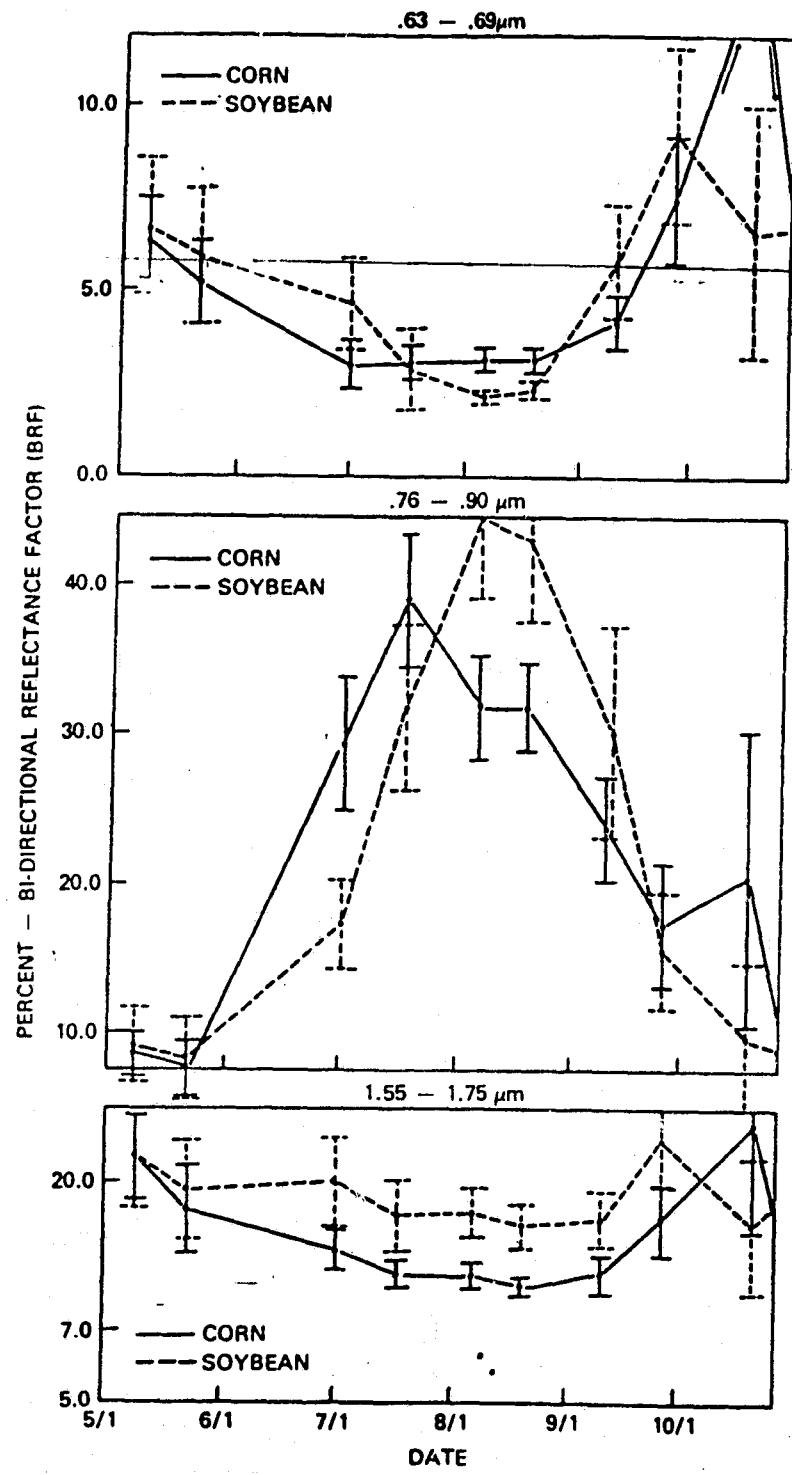


Fig. 3. Mean and variance of canopy reflectance observed with the FSS instrument for corn and soybean in Webster County, Iowa 1980 for the visible, near infrared and shortwave infrared.

Canopy Modeling

The Suits canopy reflectance model was used to evaluate possible physical explanations of the observed corn-soybeans reflectance patterns /39/. The Suits model was selected for simplicity, particularly with respect to the input parameters required. The model requires, at a minimum, specification of leaf optics, average leaf angle inclination, canopy height, leaf area index (LAI) and background soil reflectance. Leaf optics were taken from the Gausman et al. study /18/ (Fig. 2). Ground measurements coincident with the helicopter flights of plant heightgrowth stage and percentage ground cover were correlated with corn leaf angle and LAI measurements reported by Loomis et al. /40/ and soybean leaf angle and LAI measurements reported by Blad and Baker /41/. Spectral measurements from late April (before plant emergence) were used to characterize soil reflectance.

Results

With the given inputs the Suits model produced a reasonable approximation of canopy visible reflectance but significantly over estimated NIR (>50%) and the SWIR (> factor of 2) measurements (Fig. 5). In particular the model predicts that canopy reflectance is higher than soils in the SWIR band whereas the observations show the reverse pattern. The model does however predict the VIS/NIR reflectance crossover behavior and the absence of this crossover in the SWIR region. The visible and near infrared reflectance predictions originate primarily from differences in the rates the two canopies accumulate leaves (LAI) as specified in the input since leaf optics differ little between corn and soybeans in these spectral regions. However the reflectance contrasts predicted in the SWIR originate principally from differences in corn-soybeans leaf optics (Fig. 2). Corn leaves as specified in the model absorbs almost twice as much light (25% versus 15%) as the soybean leaves.

This difference is amplified by canopy multiple scattering in the model and obscures the differential temporal LAI accumulation that determines the VIS/NIR patterns. Thus despite limitations noted in the model prediction of NIR/SWIR reflectance magnitudes the model does in general replicate the relative differences observed between the crops in each spectral region.

Detailed aspects of the temporal curves including the peakedness of the NIR observations and the rapid decrease in corn NIR reflectance after tasseling are not predicted by the model. This led to concern that the canopy specifications provided the model did not fully characterize actual canopy conditions observed. Further analysis of the field observations was pursued to consider this problem.

Canopy Conditions

The agronomic measurements acquired during the helicopter flight were not able to provide further insight on canopy characteristics. The boresight color photography provided an alternative perspective on the observed canopy conditions. The photography was of sufficient quality to permit assessment of three categories of cover, percentage sunlit vegetation, percentage sunlit soil and shadow, where the sum of the three categories equals one.

Analysis

A research assistant was assigned the task of interpreting the photography. For each date over 6,000 photographs required analysis. To proceed at a reasonable rate the interpreter was instructed to visually assess the categories rather than employ dot grids or planimetry.

Preliminary experiments were carried out in which the analyst conducted interpretation of the same photographs several days apart. The results

from the different interpretation dates were the same. This provided confidence in the methodology employed. The same analyst carried out the entire interpretation to insure that at least a consistent bias was maintained in the results.

Results

The photointerpretation produced interest contrasts between the observed corn and soybeans cover conditions (Fig. 6). The sunlit vegetation in the corn canopy does not increase much beyond 60%. About 40% of the observed corn canopy consists of shadow. Soybeans never produce as much shadow as corn and continue to increase sunlit vegetation until early August at which time the canopy approaches 100% sunlit vegetation.

It is worthy of note that the sunlit vegetation temporal pattern matches well the NIR measurements for the soybeans. However the corn NIR measurements do not relate well to the sunlit vegetation pattern observed. Discussions with agronomists at the New Jersey Agricultural Experiment Station, Rutgers University led to the discovery than corn canopies following tasseling lose the lower leaves in the canopy. This loss continues throughout the remainder of growing season until senescence. Soybeans do not behave in this manner. This loss of lower leaves would not be observed in the color photography but would significantly effect canopy NIR measurements.

Percentage sunlit soil and visible measurements appear well related. This is no doubt because the low radiance from shadows is quite similar to the reflected radiance from the leaves. Thus only the presence of sunlit soil increases the observed canopy reflectance. Most interesting is the apparent inverse relation between SWIR measurements and the shadow variations with time. This leads to the speculation that differences in corn-soybeans shadowing patterns contributed to the observed SWIR reflectance contrasts

CANOPY CONDITIONS

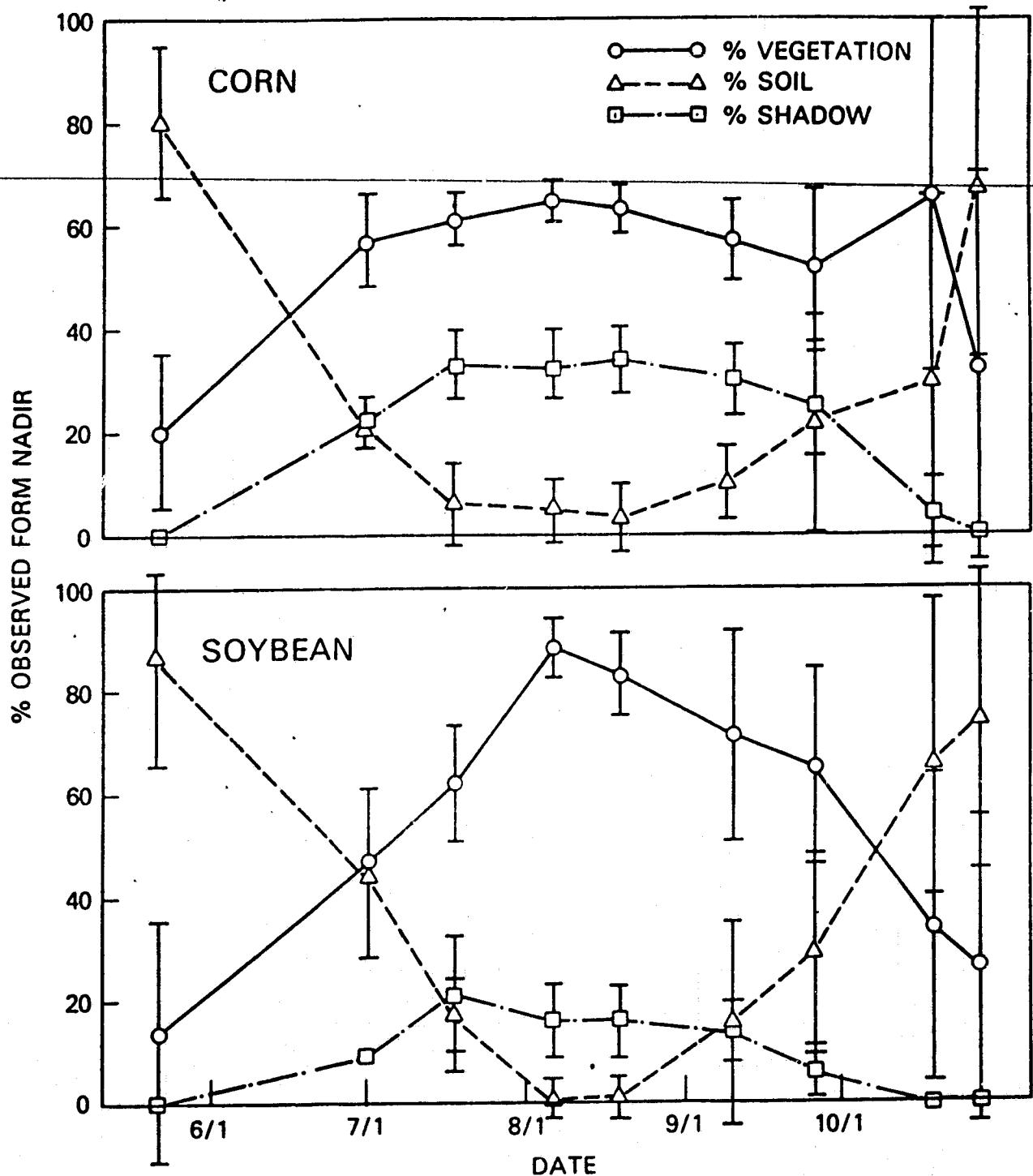


Fig. 6 Photointerpreted canopy conditions from 70mm boresight photography for corn and soybean in Webster County, Iowa 1980.

between corn and soybeans. Suits /42/ recently carried out an analysis with the row crop version of his model which supports this conclusion. However the observed differences can not originate from shadowing patterns alone. On 17 July, when the crossover behavior is observed in the VIS and NIR measurements, the corn and soybeans show similar properties of shadow, sunlit vegetation and sunlit soil (20, 60, 20). If shadow were the only cause of reflectance differences the observed reflectance differences would not occur. This shows that differences in leaf optics must contribute to the observed SWIR reflectance differences.

Discussion

The ability to discriminate corn and soybeans based at least in part of differences in leaf absorption properties raises the possibility that other vegetation species may also be discriminated with SWIR measurements. Previous studies, discussed earlier, have noted this potential for succulents and nonsucculents and potatoes versus sugar beets. The measurements by Gausman et al. /18/, when plotted on triangular graph paper, provide further evidence of this potential (Fig. 7). The triangular graph emphasizes the importance of leaf absorptance in describing the ability of measurements from differing portions of the spectrum to provide discrimination between different vegetation types. In the visible absorptance is high and the maximum absorption contrasts are less than 10% for the 18 vegetation species considered here. NIR measurements vary in relative reflectance and transmittance but show little difference in absorptance. Intensive multiple scattering in the canopy results in remotely observed NIR reflectance that is sensitive to the number and arrangement of leaves in the canopy but not the species observed. Only in the SWIR region do the absorptance differences show marked contrasts, exceeding 20% absorptance between species for the

There are two SWIR spectral bands observed with Thematic Mapper, channel 5 covering 1.55 μm to 1.75 μm and channel 7 covering 2.08-2.35 μm . The latter band was added late in the design history of TM to assist in geologic applications of TM data. For vegetation analysis the two spectral regions are often considered redundant although some evidence, not thoroughly examined, from measurements studied in this research suggests that channel 7 observations are more sensitive to the onset of senescence than channel 5. For the purpose of this paper only the 1.55-1.75 μm spectral region is considered. In addition only TM bands 3(0.63 μm -0.68 μm) and 4(0.76 μm -0.90 μm) will be contrasted with the SWIR observations. This follows the view that individual visible (VIS), near infrared (NIR) and SWIR measurements contain the majority of information on vegetation spectral reflectance contrasts because they observe differing physical phenomena, specifically pigment absorption, intercellular and canopy scattering and water absorption. Continued analysis of TM measurements will no doubt reveal more subtle variations in vegetation spectra.

The discussion presented here is the result of studies carried out over a three year period at the NASA Goddard Space Flight Center, Institute for Space Studies. The research supported the AgRISTARS program objective to incorporate TM measurements in analysis of agricultural activity. The results have implications that extend beyond agriculture and only the lack of appropriate measurements limits extending the conclusions to natural vegetation. The studies include both intensive analysis of spectroradiometer data for the AgRISTARS Corn-Soybeans Intensive Study Site and a thorough review of research literature concerned with vegetation SWIR measurements.

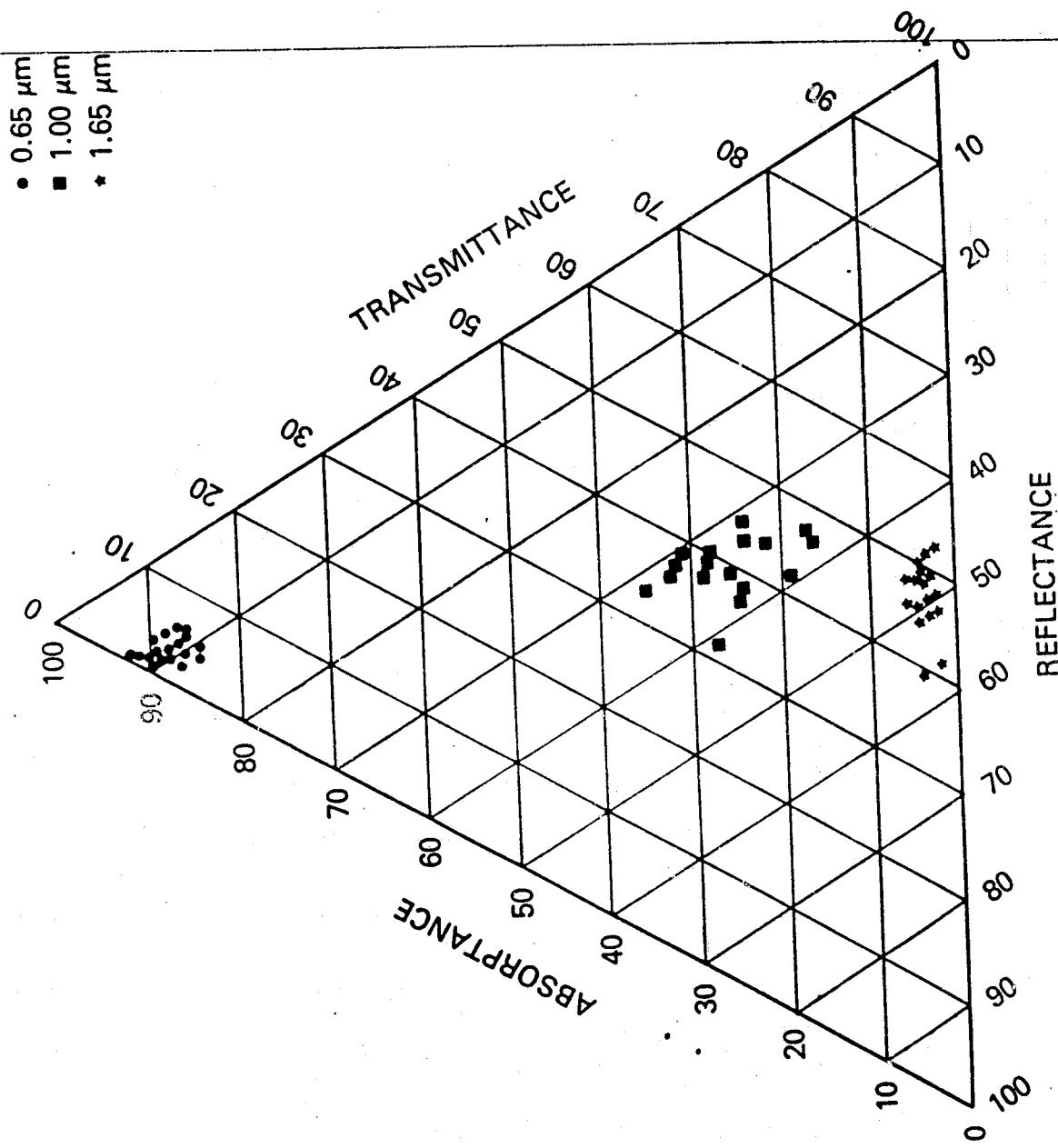


Fig. 7. Leaf optics for 18 vegetation species in the visible(0.65 μm), near infrared(1.00 μm), and shortwave infrared(1.65 μm) from Gausman et al.(18) laboratory measurements.

for a range of natural and cultivated vegetation species is necessary to take full advantage of remotely sensed SWIR measurements.

Acknowledgements

This research was supported under NASA Goddard Space Flight Center Cooperative Agreements NCC 5-20 and NCC 5-26. Cynthia Rosenswieg, from the Agricultural Experiment Station, Rutgers University, contributed significantly through intensive efforts to seek out published studies of vegetation SWIR properties. Norma Wooton is awarded the medal of endurance for having completed the photointerpretation. Stephen Ungar, NASA-GIIS, was the major source of inspiration for the research. NASA staff at the Johnson Space Center, in particular David Pitts, were most helpful and constant assistance in processing the FSS data was provided by Larry Biehl, LARS, Purdue University.

REFERENCES

1. A.B. Park, Multispectral band selection in the U.S. program, Adv. Space Research 3 (1983).
2. V. Salomonson, this issue
3. W.A. Allen and A.J. Richardson, Interaction of light with a plant canopy, J. Op. Soc. Am. 58, 372-376 (1968).
4. T.R. Sinclair, R.M. Hoffer and M.M. Schreiber, Reflectance and internal structure of leaves from several crops during the growing season, Agro. J. 63, 864-868 (1971).
5. R.M. Hoffer and C.J. Johannsen, Ecological potentials in spectral signature analysis, in Remote Sensing in Ecology ed. P.L. Johnson, University of Georgia Press, Athens, 1969, p. 363.
6. E.B. Knipling, Physical and physiological basis for reflectance of visible and near-infrared radiation from vegetation, Remote Sens. Environ. 1, 155-159 (1970).
7. J.T. Wooley, Reflectance and transmittance of light by leaves, Plant Physiol. 47, 656-662 (1971).
8. C.J. Tucker, Remote sensing of leaf water content in the near infrared, Remote Sens. Environ. 10, 23-32 (1980).
9. J.R. Thomas, V.I. Myers, M.D. Heilman and C.L. Wiegand, Factors affecting light reflectance of cotton, in Proc. 4th Symp. Remote Sens. Environ., University of Michigan, Ann Arbor, 1966, pp. 305-312.
10. R.E. Carlson, D.N. Yarger and R.H. Shaw, Factors affecting the spectral properties of leaves with special emphasis on leaf water status, Agron. J. 63, 486-489 (1971).
11. J.R. Thomas, L.N. Namkin, G.F. Oerther and R.G. Brown, Estimating leaf water content by reflectance measurements, Agron. J. 63, 845-847 (1971).
12. W.A. Allen, H.W. Gausman and C.L. Wiegand, Spectral reflectance from plant canopies and optimum spectral channels in the near infrared, in 3rd Annual Earth Resources Program Review, NASA Marshall Space Center, Huntsville, Alabama, 1973, pp. 59-73.
13. H.W. Gausman, D.E. Escobar, J.H. Everitt, A.J. Richardson and R.R. Rodriguez, Distinguishing succulent plants from crop and woody plants, Photogram. Eng. Remote Sens. 44, 487-491 (1978).
14. J.E. Dinger, The absorption of radiant energy in plants, Iowa State College J. Sci. 16, 44-55 (1941).

15. D.M. Gates and W. Tantroporn, The reflectivity of deciduous trees and herbaceous plants in the infrared to 20 microns, Sci. 115, 613-616 (1952).
16. A. Aboukhaled, Optical properties of leaves in relation to their energy-balance, photosynthesis, and water use efficiency, Ph.D. Thesis, University of California at Davis, 1966, 139 p.
17. T.R. Sinclair, Pathway of solar radiation through leaves, M.S. Thesis, Purdue University, West Lafayette, Indiana, 1968.
18. H.W. Gausman, W.A. Allen, C.L. Wiegand, D.E. Escobar, R.R. Rodriguez and A.J. Richardson, The Leaf Mesophylls of Twenty Crops, Their Leaf Spectra, and Optical and Geometrical Parameters, USDA Tech. Bull. 1465, Weslaco, Texas, 1973.
19. R. Willstatter and A. Stall, Untersuchungen über die Assimilation der Kohlensäure, Springer, Berlin, 1968.
20. W.A. Allen, H.W. Gausman, A.J. Richardson and J.R. Thomas, Interaction of isotropic light with a compact plant leaf, J. Opt. Soc. Amer. 59, 1376-1379 (1969).
21. H.T. Breece, III and R.A. Holmes, Bidirectional scattering characteristics of healthy green soybean and corn leaves in vivo, Appl. Opt. 10, 119-127 (1971).
22. W.A. Allen, H.W. Gausman, A.J. Richardson and C.L. Wiegand, Mean effective optical constants of thirteen kinds of plant leaves, Appl. Opt. 9, 2573-2577 (1970).
23. R. Kumar and L. Silva, Light ray tracing through a leaf cross section, Appl. Opt. 12, 2950-2954 (1973).
24. C.J. Tucker and M.W. Garrett, Leaf optical system modeled as a stochastic process, Appl. Opt. 16, 635-642 (1977).
25. J.E. Colwell, Vegetation canopy reflectance, Remote Sens. Environ. 3, 175-183 (1974).
26. M.E. Bauer, L.L. Biehl, C.S.J. Daughtry, B.F. Robinson and E.R. Stoner, Final Report Agricultural Scene Understanding and Supporting Field Research, NASA contract 112879, LARS Purdue University, West Lafayette, Indiana, 1979.
27. R. Kumar and L. Silva, Statistical separability of agricultural cover types in subsets of one to twelve spectral channels, in Proc. 9th Symp. Remote Sens. Environ. Environ. Research Institute Michigan, Ann Arbor, 1974, pp. 1891-1903.
28. L.L. Biehl and L.F. Silva, A multilevel multispectral data set analysis in the visible and infrared wavelength regions, Proceeding IEEE 63, 164-175 (1975).

29. L.L. Biehl and L.F. Silva, Machine aided multispectral analysis utilizing Skylab thermal data for land use mapping, in Proc. Machine Processing of Remotely Sensed Data Symp., LARS Purdue University, West Lafayette, Indiana, 1975, pp. 4B3-4B12.
30. S.G. Ungar and S.N. Goward, Enhanced crop discrimination using the mid-IR (1.55-1.75 μ m), Adv. Space Research 3, 291-295 (1983).
31. D.E. Pitts, G.D. Badhwar, D.R. Thompson, K.E. Henderson, S. Shen, C. Sarenson and J.G. Carnes, Evaluation of corn/soybeans separability using Thematic Mapper and Thematic Mapper simulator, IEEE Trans. Geosciences Remote Sensing, GE-22 (1984).
32. N.J.J. Bunnik, The multispectral reflectance of shortwave radiation by agricultural crops in relation with their morphological and optical properties, H. Veenman and Zonen B.V., Wageningen, The Netherlands, 1978.
33. D.S. Kimes, B.L. Markham, C.J. Tucker and J.E. McMurtrey, III, Temporal relations between spectral response and agronomic variables of a corn canopy, Remote Sens. Environ. 11, 401-411, 1981.
34. M.E. Bauer, C.S.T. Daughtry and V.C. Vanderbilt, Spectral-agronomic relationships of corn, soybean and wheat canopies, Tech. Report 091281, LARS Purdue University, West Lafayette, Indiana, 1981.
35. B.L. Blad, J.M. Norman and B. Gardner, Field Measurements and Simulation Modeling of Corn and Soybean Moisture Stress, 1981, Field Studies, University of Nebraska, Tech. Report NAS9-15466, 1982.
36. J.C. Harlen, W.D. Rosenthal, S. Clarke and J.C. Welch, Analysis of Spectral Data from Wheat, NASA Final Report, Texas A&M University, 1978.
37. T. Barnett and R. Juday, Skylab S-191, Visible-near infrared spectrometer, Appl. Opt. 16, 967-972 (1977).
38. P.H. Swain and S.M. Davis, Remote Sensing: the Quantitative Approach, McGraw Hill, New York, 1978.
39. G.H. Suits, Calculation of the directional reflectance of a vegetative canopy, Remote Sens. Environ. 2, 117-125 (1972).
40. R.S. Loomis, W.A. Williams, W.G. Duncan, A. Dovrat and F. Nunez, Quantitative descriptions of foliage display and light absorption in field communities of corn plants. Crop Sci. 8, 352-356 (1968).
41. B.L. Blad and D.G. Baker, Orientation and distribution of leaves within soybean canopies, Agron. J. 64, 26-29 (1972).
42. G.H. Suits, An analysis of spectral discrimination between corn and soybeans using a row crop reflectance model, Remote Sens. Environ., in press (1984).

species considered (corn-soybeans absorption difference is ~10% at this wavelength). These data suggest the values of SWIR measurements in vegetation discrimination. One of the great shortcomings of available leaf optics measurements is that they are predominantly for cultivated species. Considerable further measurements are required, particularly for natural species, before a general assessment of SWIR measurements in vegetation detection can be accomplished.

An alternative to comprehensive leaf optics measurements is identification of vegetation type physiological phenomena that can explain the observed differences. This author and others /30, 4, 22/ have previously put forward the hypothesis that differences in internal leaf structure between monocots and dicots, particularly in conjunction with C₃ - C₄ contrasts, explains the differences. Analysis of this hypothesis for the 18 species in the Gausman data has lead to the conclusion that this hypothesis is not valid. No pattern of relations between leaf optics and these leaf and plant types was found. Dependence on one set of leaf optic measurements makes this conclusion speculative and reinforces the need for considerable further analysis of leaf optics in relation to plant physiology.

Conclusion

One of the significant contributions that SWIR measurements from the Thematic Mapper should provide is an improved ability to distinguish between selected vegetation types. Preliminary results are already confirming this hypothesis. Detailed studies of corn and soybeans demonstrate the SWIR value in vegetation analysis. Differences in leaf absorption of SWIR radiation explain, at least in part, the observed reflectance differences.

A physiological explanation of these differences is related to amount relative air space in the leaves. Further studies of leaf optical properties